

The “Shoulder” and the “Ridge” in PHENIX

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Abstract. The observation of jet quenching in ultra-relativistic heavy ion collisions demonstrates significant energy loss of fast partons when passing through the created medium. Correlations between final-state particles at intermediate transverse momentum ($1.0 \lesssim p_T \lesssim 4.0$ GeV/c) allow for study of the medium and its response to deposited energy. Comparison of these measurements in heavy ion collisions with measurements in proton collisions show strong modification of the correlation shape and particle yields. Two new structures are created, both extended in $\Delta\eta$, one centered at $\Delta\phi = 0$ (“ridge”) and the other occurring at $\Delta\phi \approx \pi \pm 1.1$ (“shoulder”). In these proceedings, we describe the measurements of these structures that show consistency with a scenario of parton-medium interaction and response. We discuss a new analysis which selects on the angle of trigger particles relative to the reaction plane in Run7. New measurements of the centrality and p_T dependencies of the structures raise the possibility that the same production mechanism may give rise to both phenomena.

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1. Introduction

Jet suppression in heavy ion collisions poses questions about the fate of the away-side parton and its lost energy. As jet reconstruction is difficult with heavy ion background levels, we study jet physics via two particle correlations where the backgrounds are subtracted statistically[1][2][3]. We refer the reader to the descriptions of this analysis methodology within [3].

In p-p and d-Au collisions we find back to back production of jets, but in central heavy ion collisions we have the development of two new structures, one on the near-side and another on the away-side[3][4]. We demonstrate these findings in Fig.1 where we have measured these correlations in both the azimuthal angular difference, $\Delta\phi$, and the pseudo-rapidity difference, $\Delta\eta$, between two particles. In p-p collisions, shown in Fig.1(a), we see the near-side jet, narrow in $\Delta\eta$, and the away-side jet, broad in $\Delta\eta$ due to the swing of the away-side parton. In contrast, the near-side correlations in heavy ion collisions, shown in Fig.1(b), broaden in $\Delta\eta$. This structure is referred to as the “ridge”. The away-side jet is broadened in azimuth with a yield depletion around $\Delta\phi = \pi$ (hereafter called the “head”) and a yield enhancement at $\Delta\phi = \pi \pm 1.1$ (hereafter called the “shoulder”). We conjecture that the head is often dominated by jet suppression and the shoulder by medium response. Therefore separation of these regions allows study of the interaction between partons and the medium.

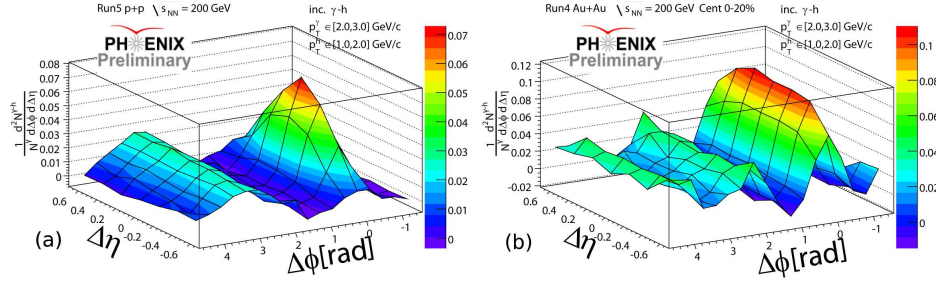


Figure 1. (Color online) Per trigger conditional yields for inclusive photons, $2 < p_T^\gamma < 3$ GeV/c, paired with charged hadron partners, $1 < p_T^h < 2$ GeV/c, in p+p and Au+Au collisions, (a) and (b) respectively.

2. Away-side Modification

We have in PHENIX two methods for decomposing the away-side structure to isolate the characteristics of the shoulder mechanism. The first, the bin method, has the advantage of being model-independent. This method measures the physics of the dominant contribution inside a fixed bin in $\Delta\phi$ and suffers in some cases due to production from multiple sources. The other, the fit method, decomposes the away-side via a multi-Gaussian fit of the form:

$$J(\Delta\phi) = A_N e^{\frac{\Delta\phi^2}{2\sigma_N^2}} + \frac{A_S}{2} \left(e^{\frac{(\Delta\phi+D)^2}{2\sigma_S^2}} + e^{\frac{(\Delta\phi-D)^2}{2\sigma_S^2}} \right) + A_H e^{\frac{(\Delta\phi-\pi)^2}{2\sigma_H^2}}. \quad (1)$$

This method has the disadvantage of being model-dependent, but should better separate contributions from multiple sources.

A extensive study of away-side correlations as a function of p_T selection has been carried out [3]. At high p_T the away-side peak is similar in shape but suppressed in yield compared to p-p collisions. Below $p_T \approx 4$ GeV/c the away-side broadens with the head being suppressed in yield and the shoulder showing yield enhancement. The latter is found to be more prominent as the associated particle p_T decreases [3].

Measurements of the shoulder $\Delta\phi$ maximum have been made via the fit method and show its location is largely independent of both partner and trigger p_T selections[3]. This disfavors theoretical models which predict a p_T dependent location.

We have also measured the away-side particle species dependence. We find that the correlation shape is similar for both meson and baryon partners. The baryon to meson ratio of per trigger associated yields increases from peripheral to central collisions. This trend is incompatible with in-vacuum fragmentation, but similar to the behavior of the inclusive baryon and meson yields. Furthermore, we have measured the away-side spectral slopes. Above N_{part} of 100 where the shoulder mechanism dominates, we find that the spectra are softer than in p-p collisions. The spectra also show the same p_T independence that has been measured in other shoulder properties but contrasts the expectation from p-p measurements[3].

Path length dependence to the away-side shoulder was probed by binning the triggers with respect to the reaction plane using the new Reaction Plane detector installed in Run7. In Fig. 2 we examine a case of little geometry variation in central 0-5% collisions and find no dependence with reaction plane. When we examine a case of large geometry variation at 30-40% centrality, we find a slight variation with reaction

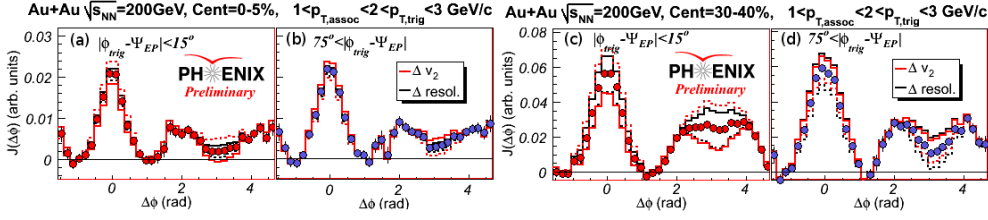


Figure 2. (Color online) Jet functions with charged hadron triggers, $2 < p_{T,trig} < 3$ GeV/c, paired with charged hadron partners, $1 < p_{T,assoc} < 2$ GeV/c. Central collisions, 0-5%, are shown in (a) & (b), in-plane and out-of-plane respectively. Mid-central collisions, 30-40%, shown in (c) & (d), again in-plane and out-of-plane respectively. Systematic errors are correlated or anti-correlated, as indicated by solid and dashed lines.

plane, but this may be covered by the current uncertainties. The anti-correlating systematic errors are influential in trend determination. As understanding of the new Reaction Plane detector improves, this key source of systematic error should improve.

3. Near-side Correlations

In the near-side, we have measured the per trigger yield with respect to p-p collisions via the ratio I_{aa} . We find that the near-side yield enhancement also appears in the same p_T range, $\lesssim 4$ GeV/c, as the away-side enhancement. The highest p_T selections again show a similarity to p-p, though now without suppression[3].

We have also measured the near-side baryon to meson ratios and find that like the away-side the trends move from p-p values towards the inclusive measurements. Since the near-side jet is not suppressed, the ratios can not achieve an inclusive-like particle mixture in the most central events[5]. Softening of spectral slopes relative to p-p is witnessed for the near-side, again similar to findings in the away-side.

We have measured the near-side distributions projected along $\Delta\eta$ compared to p-p. This verifies that the near-side enhancement measured is broad within our acceptance. Higher p_T selections match the $\Delta\eta$ profile of p-p. As seen in Fig. 1, outside of $0.5 |\Delta\eta|$ we have access to a region relatively free of p-p like production for a selection of p_T ranges[3].

4. Ridge-Shoulder Comparison

In this ridge-dominated region, we have measured the centrality dependence of the ridge yield with respect to the shoulder extracted with little contamination from the head (via the fit method). In Fig. 3 we show the ridge and shoulder have similar centrality dependencies.

We have also measured the total partner p_T in the near- and away-side, see Fig. 4. We find in a narrow pseudo-rapidity window, near-side jet and ridge components balance with the shoulder and head components. By selecting a wide pseudo-rapidity bin, we drop the near-side jet contribution and find that the remaining ridge component balances with the shoulder component alone. Possible independent production of ridge and shoulder leads to no expectation that this should be so. Using this technique we have also measured the shoulder and ridge spectra and confirm that

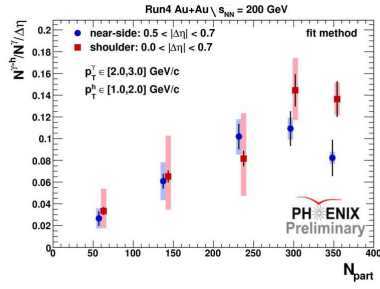


Figure 3. (Color online) Per trigger conditional yields in the ridge-dominated near-side $\Delta\eta$ bin (circles) and in the shoulder component (squares) by N_{part} in Au+Au collisions.

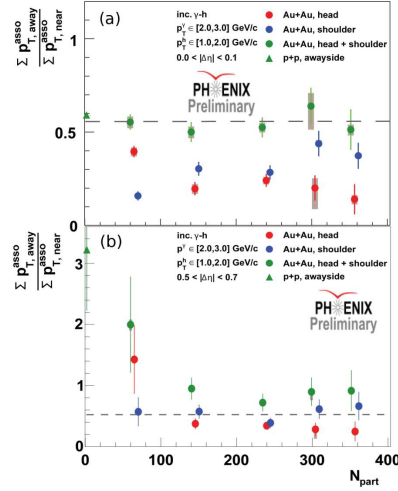


Figure 4. (Color online) p_T ratios between away-side sources and $\Delta\eta$ -binned near-side partners

the spectra are softer than their p-p counterparts. The shoulder is closest to the inclusive spectral slopes with the ridge being slightly harder[6].

The ridge-shoulder similarity found in so many of the measurements may be the result of triggering on the medium response. If the true shoulder mechanism is two-sided and broad in $\Delta\eta$, a trigger arising from the medium response would pair with other medium response particles at both 0 and $2\pi/3$. We have evidence from I_{aa} reported in [3] that the triggers below $\lesssim 7$ GeV/c have significant contributions other than jet fragmentation. Triggers from jet fragmentation and medium response would mix ridge and shoulder production (should they be produced separate phenomena at all) and could be responsible for some of the similarities witnessed in the data.

5. Conclusions

PHENIX is performing measurements of both the ridge and the shoulder. Both structures are inconsistent with in-vacuum jet fragmentation. The ridge and the shoulder share much of the same behavior. They appear at similar p_T . They have a similar centrality dependence. They are softer than their p-p counterparts. They have baryon to meson ratios larger than jet fragmentation. And, finally, they balance in p_T . These similarities suggest that the ridge and shoulder may share a common production mechanism.

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